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Effects of Ambient Environment on the Storage of Switchgrass for Biomass to Ethanol and Thermochemical Fuels

John S. Cundiff
Lori S. Marsh

Department of Biological Systems Engineering
Virginia Tech
Blacksburg, Virginia 24061-0303

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1.0 INTRODUCTION

A fiber conversion plant will require a year-round feedstock supply, consequently storage is a key issue. Large round bales can be stored outside on crushed rock with dry matter losses as low as 15% of initial dry matter. If biomass sells for $65/dry Mg, the storage loss is worth 0.15 x 65 = $9.75/dry Mg. With an outside storage system, storage "cost" is then $9.75/dry Mg. Accurate dry matter loss vs. storage time data is needed to calculate the cost of ambient storage.

Composition change during storage and potential impact on conversion is also a matter of concern. Previous hay storage studies have shown that percentage of neutral detergent fiber (NDF) increases and percentage of acid detergent fiber (ADF) increases because of composition change.

2.0 REVIEW OF LITERATURE

2.1 Small Rectangular Bale Storage

Much has been learned about changes in small rectangular bales during inside storage. When hay is baled too wet, spontaneous heating results and retention of nutrients is lowered Hoffman and Bradshaw (1937). Nelson (1972) found that retention of dry matter, organic matter, non-nitrogenous substances, crude fat, carbohydrates and nitrogen-free extracts decreased in native grass bales as moisture content at baling increased. Retention of these properties was almost independent of bale density (wet basis) at baling.

2.2 Round Bale Storage

A major advantage of the round bale is that it can be stored outside. The rounded top surface sheds water much like a thatched roof. Exposure to sunlight, and wetting and drying cycles cause different compositional changes in the outer layer, sometimes referred to as, "the shell", versus, "the core". Researchers have struggled to find a sampling method that adequately characterizes changes in a round bale stored outside.

2.2.1 Round Bale Sampling Techniques

Sampling has been done by drilling a core from the outer surface to the center of the bale using a Penn State sampling tool. The percentage of weathered hay in this core is lower than the percentage of weathered hay in the bale. Suppose a 5 ft-in diameter by 4 ft-wide bale with a four-inch weathered-layer is being sampled by drilling a one-inch diameter hole to the center. The four-inch thick weathered-layer is 13% of the drilled core. Volume in the four-inch outer layer is 25% of the bale volume. Influence of the weathered layer is underestimated by an analysis of the drilled core.

Bledsoe and Bales (1991) drilled separate samples from the shell (10.5 inches thick outer-layer) and the core (volume from inside surface of shell to center of bale). They reported compositional change in the shell and core portions separately after an eight-month storage.

Harrigan and Rotz (1992) sampled by boring to a four-inch depth to define the weathered layer. The core was defined by boring from four inches to the center of the bale; a depth of 24 inches. Four samples were collected at each depth from the top, bottom, and both sides (32 samples per bale). Samples from each depth (16 samples) were combined and analyzed as representative of the bale layer.

Russell et al. (1990) sampled round bales of alfalfa-bromegrass. They sampled at three-inch intervals to a depth of 12 inches into the bale, and from 12 inches to the center of the bale at 25% of the bale's length on both sides. The cores were drilled in a plane parallel to the ground. Cores were drilled in the top and bottom at 50% of the bale length. After core-sampling, bales were tub-ground and "grab" samples collected. These samples were taken to be representative of the entire bale.

The core samples were weighted according to the portion of the bale volume they represented, and these weighted values used to calculate the amount of a given component in the bale. The correlation coefficient for NDF, based on the weighted core samples and the tub-ground samples, was 0.93. For the ADF and in-vitro digestible dry matter (IVDDM), it was 0.90 and 0.91, respectively. This level of agreement between the two procedures indicates that the coring technique gave a good estimate of the average value for the bale.

2.2.2 Temperature Rise in Round Bales

When hay is baled at a moisture content above 20%, microbial activity produces a temperature rise which potentially, depending on amount of rise and duration, can cause a compositional change. Dobie and Hag (1980) baled round bales of rice straw at moisture contents ranging from 20% to 50%. At 20% to 30% moisture content, a moderate temperature rise occurred during the first 15 to 20 days of storage, and then bale temperature cooled to ambient. Bales at 40% to 50% moisture heated to 65°C within two days and maintained an elevated temperature for nearly 60 days.

Montgomery et al. (1986) baled large round bales of alfalfa-orchardgrass at 23, 17.5, and 13% moisture. Significant heating (temperatures up to 90°C) occurred in the 23% bales, and some elevated temperature in the 17.5% bales. Reduction in nutritional value of hay due to heating was observed.

2.2.3 Dry Matter Loss from Round Bales Stored Outside

If hay is baled at low moisture and protected from the weather, losses from round bales are low, generally in the range of 3% to 5%. Round bales stored outside without cover are subject to weathering. Rainfall leaches out soluble solids, and sunlight causes a breakdown of some compounds. Weathering of grass hay in Indiana studies was generally confined to the outer 5 to 10 cm of large round bales (Smith et al., 1974). Outside storage is a low cost option; consequently, it is of interest to those planning year-round supply of herbaceous feedstock to a conversion plant.

Rider et al. (1979) used the illustration in Fig. 2.1 to describe the events that affect round bales in outside storage:

- As a round bale settles, approximately one-third of the circumference contacts the ground;
- A substantial amount of moisture can be absorbed through the bottom of the bale resulting in spoilage as far up as 30 cm;
- If weather affects the outer 15 cm around the entire circumference, plus an additional 15 cm at the bottom, 42% of the bale volume can be affected;
- If the bottom is protected, the exposed top two-thirds of the circumference (15 cm depth) represents more than 20% of the mass.

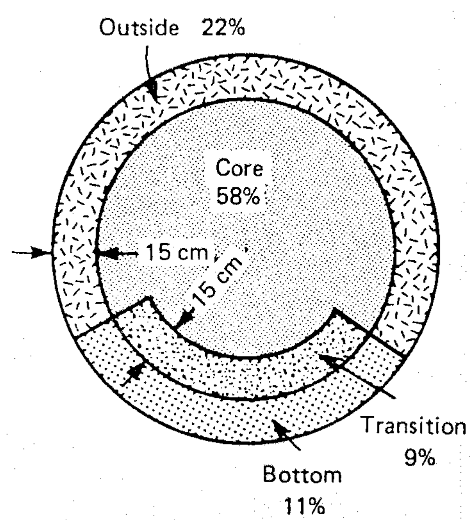

Figure 2.1. General description of round bale loss profile. [Reprinted from Rider et al. (1979).]

Determination of dry matter loss depends on four measurements: initial moisture content, initial weight, final moisture content, and final weight. With reasonable care, an accurate initial and final weight can be determined. It is difficult, however, to determine the average initial and final moisture contents.

The windrow over the area being baled must be sampled multiple times (10 or more) to get a composite sample that will give a reasonable estimate of the moisture content of hay baled into the bale. Bales exposed to weather, particularly in areas with frequent rainfall, have a variable moisture content after storage. The outer-layer (four inches) moisture content varies based on when the last rain occurred. Moisture content of the next layer, identified as a transition layer, changes based on season. During the winter when drying conditions between rain events are poor, the moisture content of this layer tends to be higher than it is during the spring when more drying takes place between rain events. As ambient conditions improve into the spring, the transition layer dries to a moisture content approximately equal to the core. Core moisture content changes very little during storage. If the hay is baled above 15%, the core hay will typically drop in moisture during storage and end up between 10% and 20%.

The problem of determining average moisture content after storage is complicated by the fact that the boundary of the transition layer changes with time. In early winter, the transition layer is relatively thin; in late winter, it is thick; in late spring, it is thin. No sampling technique has been agreed upon for determination of a true average moisture content for round bales stored outside. This fact should be remembered in interpreting dry matter loss data in the literature.

Dobie and Hag (1980) stored round bales of rice straw outside in California. Perhaps in recognition of the difficulty in making an accurate dry matter loss measurement, Dobie and Hag make this statement, "Weights of bales taken at time of baling and again at time of sampling, when corrected for moisture content, indicated no measurable losses in dry matter with the level of precision available for these test conditions."

Marley et al. (1976) baled round bales of clover and alfalfa hay in Iowa at moisture contents ranging from 20% to 45% (w.b.). Dry matter loss after 45 days of storage is shown in Table 2.1. At a baling moisture content of 21%, dry matter loss was 9%. When baling moisture content was 35%, dry matter loss increased to 24%.

Measured losses can vary widely based on ambient weather. Nelson et al., (1983) baled ryegrass at 20% moisture content and stored uncovered bales outside on an eight-inch gravel bed and on the ground. Dry matter loss after seven months ranged from 27.6% (ground) to 31.2% (gravel). Total rainfall during the storage period was 20 inches.

Table 2.1. Dry Matter Loss from Round Bales of Clover and Alfalfa after 45 Days of Outside Storage[1].

Moisture Content at Baling (% w.b.)	Dry Matter Loss (% of Day 1)
44.8	18.9
35.2	23.8
31.3	14.0
26.9	11.1
21.1	9.1

[1]Reprinted from Marley et al. (1976).

High dry matter losses have also been measured in Canada. Atwal et al. (1984) stored round bales of alfalfa baled at 20% moisture. For hay stored outside six months, total dry matter loss (oxidation, weathering, and hay discarded to remove visible mold growth) was 40%.

Anderson et al. (1981) stored uncovered round bales of alfalfa on the ground in Pennsylvania and measured a 14% dry matter loss. Huhnke (1988) baled alfalfa in 5-ft-diameter by 4-ft-long round bales and stored them on the ground and on pallets. Average bale density was 11.3 lb/ft^3 and moisture content at baling was 11.2%. Dry matter loss measured over the eight-month storage was 8.6% for the bales on pallets and 13.1% for bales on the ground.

Harrigan and Rotz (1992) stored round bales of alfalfa outside in Michigan for six to nine months. Average dry matter loss for 4 ft diameter bales, wrapped in net, was 16.3%, as compared to 16.5% for string-wrapped bales.

Kjelgaard et al. (1981) found that unprotected outdoor storage of round bales resulted in 10% to 15% dry matter loss. Most deterioration occurred in the 20-cm deep outer layer.

Round bales of alfalfa stored in southern Wisconsin had a 9.1% dry matter loss in 1980 and 10.9% in 1981 Collins et al. (1987). Losses from bales elevated off the ground were 7.5% in 1981.

Bale size can be expected to have an influence on dry matter loss during storage. The largest round bale is 6-ft in diameter and 5-ft-long. Huhnke (1990) stored 6 ft x 5 ft bales of bermudagrass in Oklahoma. Average density achieved with a variable-chamber (V-C) baler was 9.2 lb/ft^3 and a fixed-chamber (F-C) baler gave a density of 8.5 lb/ft^3. Moisture content at baling was 15%. Uncovered F-C bales stored on the ground lost

9.7% dry matter in a row oriented East-West and 14.1% in a North-South row. Individual bales (not in a row) lost 12%. V-C bales in a North-South row lost 7%. Losses for bales stored in a North-South row on pallets ranged from 3.8% (V-C bale) to 10% (F-C bale).

Round bales of switchgrass baled with twine and net were stored on sod and crushed rock at two locations in Indiana (Johnson et al., 1991). At the end of nine months of storage, they separated the switchgrass into a weathered fraction and an unweathered fraction. Weathered hay was subjectively determined as material that livestock would not consume. Material remaining on the ground after the bale was lifted was collected with a pitchfork and combined with the other weathered-material to form a fraction identified as "recoverable weathered". Combined results for the two sites (Table 2.2) show that storage on rock gave a higher dry matter recovery for string-wrapped bales (98.1% vs. 96.7%). A recovery of 96% to 98%, indicating a loss of only 2% to 4%, is quite high compared to other studies with grass hay.

Table 2.2. Dry Matter Recovery from Large Round Bales of Switchgrass Baled with Twine and Net and Stored on Sod or Crushed Rock in Indiana[1].

	Twine			Net		
Storage Surface	Unweathered	Recoverable Weathered	Total	Unweathered	Recoverable Weathered	Total
	% of Original Dry Matter					
Sod	80.7	4.5	85.2	92.3	4.4	96.7
Rock	92.5	3.7	96.2	95.5	2.6	98.1

[1]Reprinted from Johnson et al. (1991).

Wiselogel et al. (1994) stored round bales of switchgrass in central Texas and measured a 13% dry matter loss at 8.5 months. Depth of the weathered-layer was 19 cm (7.5 in.), and total rainfall received during the storage period was 65 cm (25.5 in.).

2.2.4 Variability in Dry Matter Density and Moisture Content within Round Bales

As stated by Bledsoe et al. (1992), the factors affecting mean dry matter density of large round bales are:

- Type of bale chamber (fixed or variable geometry),
- Tension adjustment on chamber bale-rolling mechanism,
- Material density of windrow,

- Forward speed of baler along windrow (feed rate of material into baler),
- Species being baled, and
- Moisture content.

Bledsoe et al. (1992) drilled numerous cores to determine moisture content distribution in bales produced with the tension control of the rolling mechanism set to make dense bales. For a bale with average moisture content of 16.9%, the moisture content ranged from 12% to 22%. Dry matter density in this same bale ranged from 64 to 256 kg/m^3, a four-to-one variation.

Bledsoe et al. (1992) collected grab samples from 10 swath locations and combined these samples to determine moisture content at baling. For two bales, the moisture content determined by this method was 16.8% and 15.8%. Average moisture content, determined by coring these bales, was 16.9% and 15.8%, respectively, indicating that the swath sampling method was an accurate procedure. Coring of a third bale revealed an average moisture content of 17.7%, but the swath sampling method gave a moisture content of only 13%. It is apparent that a poor estimate of at-baling moisture content can be obtained with the swath sampling method. Since initial moisture content is a key parameter in the calculation of dry matter change during storage, an accurate procedure is essential.

2.2.5 Compositional Change in Round Bales Stored Outside

Most of the round bale storage studies have been directed toward determining digestibility by rumens. This literature is reviewed because the analysis done for ADF, NDF, and crude protein (CP) in this research used the same forage analysis methods commonly reported in the literature. Our results can be compared directly to the literature reviewed here. Compositional analyses are typically presented as a concentration of the component expressed as a percent of dry matter. Some studies compare concentrations at baling with concentrations after storage, and give a percentage change. This procedure can obscure information on compositional change as shown by the following example:

> NDF is the measure of cell wall constituents. Suppose the initial NDF concentration is 55%. Quantity of NDF in 100 units of dry matter is:
>
> $$0.55 \times 100 = 55$$
>
> Assume there is a 15% decrease in solids caused by the leaching of solubles from the hay. Concentration of NDF, assuming no loss of cell wall material, is:
>
> $$\frac{55}{100\ (1 - 0.15)} \ x\ 100 = 64.7\%$$

There is an apparent increase in cell wall constituents of:

$$\frac{(64.7 - 55)}{55} x\ 100 = 17.6\%$$

Actually, the cell wall constituents have not changed. The reader is reminded of this possible misconception when interpreting the following compositional change data.

2.2.5.1 Compositional Change in Legume Hay Baled in Large Round Bales and Stored Outside

Marley et al. (1976) found that crude protein (% dry matter) in alfalfa increased during 3.5 months of storage by only 1.2%. Results were averaged for bales having moisture contents at baling ranging from 21% to 45%. The proteinaous material did not decrease at the rate of the non-proteinaous; consequently, there was an apparent increase in protein.

Huhnke (1988) found that CP increased 12% to 13% in the outer layer and 7% to 10% in the whole bale, a much higher increase than the 1.2% measured by Marley et al. (1976) the 3% measured by Anderson et al. (1981), and the 0% to 0.4% measured by Harrigan and Rotz (1992). Change in ADF measured by Huhnke (1988) was quite small, 2.5% in the outer layer and -2.5% in the whole bale, whereas Anderson et al. (1981) measured a 19% increase, and Harrigan and Rotz (1992) measured a 5% to 6% increase in the outer layer and a 1.5% to 2.5% increase in the core.

NDF change is expected to be quite variable, depending on rainfall and subsequent leaching during storage. Harrigan and Rotz (1992) found an increase of 8% to 9% in the outer layer and 3% to 4% in the core. Collins et al. (1987) reported a 4% increase for the whole bale. Huhnke (1988), however, reports a 23% to 25% increase in the outer layer and 7% to 9% increase for the whole bale. Some of this range in reported NDF change may be due to (1) differences in the way measurements were made, and (2) differences in the way percent change was calculated.

2.2.5.2 Compositional Change in Grass Hay Baled in Large Round Bales and Stored Outside

Nelson et al. (1983) stored ryegrass bales on gravel and on the ground for seven months in Louisiana. NDF changed very little, from 67% to 70% of dry matter for bales stored on gravel and from 69% to 71% for bales on the ground. Change in ADF was larger, 41% to 45% on gravel and 43% to 46% on the ground. CP went from 9.2% to 11.6% on gravel and 8.9% to 11.4% on the ground. They reported dry matter losses of 31% on gravel and 28% on the ground, so the hay was severely impacted by weather. It is interesting that the composition of hay from the weathered bales was not greatly different from the initial composition.

Bermudagrass bales made with a variable-chamber baler were stored on the ground in Oklahoma Huhnke (1990). NDF changed from 72% to 76%, ADF from 36% to 38.5%, and CP from 12.6% to 12.2%. IVDMD changed from 51% to 46.5%. NDF was higher in the bermudagrass than the ryegrass Nelson et al. (1983). Dry matter loss reported for the bermudagrass bales was 7%, as compared to 28% to 31% for ryegrass bales in Louisiana.

Bledsoe and Bales (1991) stored mixed-grass hay in Tennessee and report a CP recovery (final composition/initial composition) of 109% to 122% for hay from the shell (outer layer), 101% to 114% from the core, and 105% to 118% weighted average for the bale. These figures are comparable to 126% recovery for bales on gravel and 128% recovery for bales on the ground in the study done by Nelson et al. (1983). As observed for alfalfa hay, the CP of grass hay appears to increase during storage. Two factors explain this apparent increase:

1. Dry matter loss due to weathering (leaching of solubles, breakdown of molecules by sunlight) and due to microbial action reduces the dry matter content of the bale. CP expressed as a percentage of dry matter increases.

2. Non-proteinaous materials breakdown faster than proteinaous, thus the ratio of the two increases.

Bledsoe and Bales (1991) report an IVDDM recovery ranging from 78% to 85% for their mixed-grass hay, while Nelson et al. (1983) report better than 93% recovery for ryegrass. Recovery of bermudagrass was 91% (Huhnke, 1990).

Two studies were found in the literature on switchgrass. Johnson et al. (1991) stored round bales of switchgrass in Indiana and found that NDF was 74% in unweathered hay, 75% in weathered hay and 76% in a composite sample. ADF was 44% unweathered, 49% weathered, and 45% composite. CP was not measured directly, but nitrogen (N) was reported at 1.1% to 1.5%. Change in NDF, ADF, and N over the storage period was very low—less than one percentage point, indicating that switchgrass stores well.

Wiselogel et al. (1994) report composition data on round bales of switchgrass stored outside for 6.5 months. In recognition of the difficulty of calculating a true compositional change when the soluble solids are leached during storage, they present their results as a percent of dry matter (extractive-free basis). At the beginning of storage, glucan, taken as a measure of cellulose, was 37.3%. Extractives were 17%, thus the conversion to a whole biomass basis is obtained by dividing by the factor:

$$[1 + 17/(1 - 17)] = 1.2048$$

Cellulose concentration on a whole biomass basis was:

$$37.3/1.2048 = 31\%$$

The hemicellulose content was approximately equal to the sum of uronic acids (1.4%), arabinan (3.3%), xylan (24.6%), mannan (0.3%), and galactan (1.1%), for a total of 30.7%. Converting to a whole biomass basis, hemicellulose was 30.7/1.2048 = 25.5%. Total lignin was 21.3%, or 17.7% on a whole biomass basis.

There is not a good way to compare the results of Johnson et al. (1991) and Wiselogel et al. (1994). An approximation of hemicellulose is obtained by subtracting ADF from NDF. Based on the Johnson et al., results, hemicellulose is 76-45 = 31%, which compares to the 25.5% reported by Wiselogel et al. Theander and Westerlund (1993) have reported that determination of hemicellulose content based on the gravimetric difference between NDF and ADF tends to overestimate hemicellulose; thus, one would expect the Johnson et al. results to be higher.

Change in composition during storage was quite low in the Wiselogel et al. study. Separate analyses were done for inside hay (core) and outside hay (weathered layer). Change in total lignin was 0.8% for the inside hay and 1.5% for the outside. Cellulose decreased about 2% in both the inside and outside based on the extractives-free composition. The major change was in extractives, which decreased 7.9% in the inside hay and 10.6% in outside hay.

2.3 Summary

Heating of large round bales occurs when they are baled at a moisture content greater than 20%. This heating degrades some protein such that it cannot be digested by the rumen; consequently, heating is a disadvantage when hay is fed to cattle. Research must show whether heating is a significant disadvantage for hay used for fiber conversion. Cost to harvest biomass is reduced when equipment annual operating hours are maximized. Being able to bale at a higher moisture content gives the equipment owner more potential operating days during the harvest season.

A sampling method that accurately determines average moisture content of a round bale stored outside for six months is needed. This measurement must be correctly done in order to calculate dry matter loss during storage.

The range of reported dry matter loss from unprotected round bales of legume hay stored on the ground range from 7% to 40%. Most of the data is clustered in the 13% to 18%

range. Results for grass hay are similar. Dry matter losses of 14% were reported for bermudagrass stored in Oklahoma, 13% for switchgrass in Texas, 28% for ryegrass in Louisiana.

Very little change in NDF or ADF was measured in the ryegrass study in Louisiana or the bermudagrass study in Oklahoma. The switchgrass study in Indiana reported less than one percentage point change.

The effects of changes during storage on the conversion processes currently being studied are not known. There is some justification for using IVDDM as a surrogate indicator.

Bledsoe and Bales (1991) report an IVDDM recovery (after storage/initial) of 78% to 85% for their mixed-grass grass hay, while Nelson et al. (1983) report better than 93% recovery for ryegrass. Recovery of bermudagrass was 91% Huhnke (1990). Based on these results, it appears that reduction in IVDDM of herbaceous biomass may range seven to 22 percentage points. Reduction in conversion potential to liquid fuel has not been defined.

3.0 OBJECTIVES

This study was undertaken to quantify the storage loss and compositional changes of switchgrass (*Panicum Virgatum L.*) during ambient storage. Potential for conversion of the storage fiber was evaluated by NREL. Specific objectives of the research undertaken at Virginia Tech were:

1. Determine dry matter loss and compositional changes in 6 ft-diameter x 4 ft-long round bales destructively sampled at 4, 8, and 12-months over a 12-month ambient-storage period.

2. Determine dry matter loss and compositional changes in 6 ft x 4 ft round bales over a 12-month storage period when the hay is rained on after cutting, then dried to below 15% moisture content before baling.

4.0 METHODS AND MATERIALS

4.1 Switchgrass Establishment

Herbicide was applied to an 11.1 acre field that had been managed for hay production. The field had an excellent stand of clover and mixed-grasses, predominantly fescue. Roundup was applied with a boom sprayer at the rate of 3.25 qt/acre mixed in 30 gal water/acre. At the time of application (May 5, 1993), vegetation was 12 inches high and growing rapidly. Application cost was $3.50/acre plus cost of herbicide ($11.50/qt x 3.25 qt/acre = $37.50/acre) for a total cost of $41.00/acre.

The Roundup did not kill the clover so a second herbicide application (one pt/acre Banvil, one qt/acre 2,4-D in 30 gal water/acre) was applied on May 20, 1993, at a total cost of $17.75/acre. The field was burned on June 1, 1993. A brisk wind was blowing. First a firebreak was burned on the downwind side of the field, then the upwind side was ignited and the entire field burned. Two workers with backpack sprayers easily kept the fire under control. Estimated cost of burning was $3.00/acre.

The field was sprayed in the morning and seeded in the afternoon of June 17. Herbicide (one qt/acre Paraquat, one qt/acre Roundup in 30 gal water/acre) was applied to control weeds that had emerged since the field was burned. Cost of this third spraying was $18.70/acre herbicide + $3.50/acre application for a total of $22.20/acre.

Alamo was seeded using a no-till planter (Hay Buster) calibrated for a 10 lb/acre seeding rate and operated at 3.8 mph. Cost of planting was $10.00/acre and cost of seed was $3.75/lb x 10 lb/acre = $37.50/acre for a total cost of $47.50/acre.

Since the field was being established for research purposes, it was desirable to obtain as pure a stand as possible. A fourth herbicide application (three pt/acre, 2,4-D, one pt/acre Banvil, two pt/acre Simazine in 30 gal water/acre) was applied on July 28 to control broadleaf weeds. Total cost of this fourth spraying was $20.35/acre herbicide + $3.50/acre application for a total cost of $23.85/acre. Broom sedge was competing with the switchgrass in parts of the field, and it was hoped this herbicide application would reduce this competition.

A summary of the establishment cost is given in Table 4.1. Total cost was $155.30/acre. For a production operation, it is probable that a farmer would not apply the fourth herbicide application, so establishment cost would be $131.45/acre ≈ $130.00/acre.